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AFRL-SR-BL-TR-00-

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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 15, 2000		3. REPORT TYPE AND DATES COVERED Final report	
4. TITLE AND SUBTITLE HRR TOS/TOM Features and Classifiers using Boundary Methods				5. FUNDING NUMBERS AFOSR grant F49620-97-1-0518	
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The Ohio State University Department of Electrical Engineering 2015 Neil Ave. Ohio State University Columbus, OH 43210				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION STATEMENT A Approved for Public Release Distribution Unlimited				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 Words) This project is focused on the development of features and classifiers for TOS/TOM classifiers, specifically for HRR applications. Our technical approach to this problem is broken into two parts: 1) feature generation and feature set evaluation, and 2) classifier design. We are evaluating both data-driven and physics-based models to produce features to determine which set(s) of features are robust to the differences between measured and synthetic data. Feature Set Evaluation (FSE) is accomplished using both conventional techniques (e.g., kNN) and using a technique called Boundary Methods. New classifier designs are being developed that use these features to construct classifiers and verify that the developed classifiers perform well when trained with synthetic data and tested on measured data. Moreover, we verify that the classifiers make efficient use of a limited set of stored templates in order to mitigate computational problems.					
14. SUBJECT TERMS ATR, feature-set design, feature-set evaluation, classifiers, TOS/TOM				15. NUMBER OF PAGES 6	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT		20. LIMITATION OF ABSTRACT	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

DTIC QUALITY INSPECTED 4

HRR TOS/TOM Features and Classifiers using Boundary Methods
AFOSR grant F49620-97-1-0518
Final Report
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Introduction

It is well established that a persistent problem associated with construction of High-Range Resolution (HRR) classifiers arises because of the large numbers of targets which must be classified - each of which can be arbitrarily oriented and/or configured. Collecting a completely representative set of measured signatures for all targets, configurations, and orientations is infeasible and prohibitively expensive. Consequently, for a realistic fieldable system, synthetic signatures must be used to construct the classifier, but the classifier will subsequently be required to operate using measured signals.

While synthetic training data may, in some cases, faithfully represent the primary scattering phenomena for a target, measured signatures for the same targets can be quite different. These differences arise from variations in reflectivity, interaction between scatterers, radar system ambiguities, sensor and environment noise, and model mismatch. These subtle, but critical, differences are not always captured in synthetic signatures. As a result, classifiers which use simple metrics, such as MSE, to determine the similarity between measured and synthetically generated signatures can perform poorly since distance measures of this type can be strongly influenced by the numerous, though relatively small, differences in the measured and synthetic signatures. We refer to this problem as the TOS/TOM problem, which stands for Train-On-Synthetic/Test-On-Measured. While this problem is a central concern in both air-to-air and air-to-ground HRR systems, the TOS/TOM problem also arises in many modern ATR systems which rely on synthetic training data - regardless of the sensing modality.

Heuristic solutions to the TOS/TOM problem, for example computing Mahalanobis distance for several downrange shifts of the synthetic templates to determine the best match, i.e., the best correlation, with the measured signature can:

- a) be computationally inefficient and/or require extensive storage,
- b) neglect effects caused by target motion, e.g., continuous sub-range-bin scatterer shifts, and,
- c) be unduly influenced by the contributions of small-valued scatterers.

These factors suggest that considering alternative features that are less susceptible to the differences in measured and synthetic data might result in a more robust classifier. Accordingly, this research focuses on developing a general design methodology for constructing efficient HRR classifiers that perform well when trained on synthetic data and tested on measured data. In particular, the methodology should result in a set of features and a classifier design that is more forgiving and efficient than, e.g., a Mahalanobis distance classifier with respect to differences between measured and synthetic signatures.

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Our technical approach to this problem is broken into two parts: 1) feature generation and feature set evaluation, and 2) classifier design. Over the past year this project has concentrated primarily on classifier design.

With respect to feature generation we are currently generating alternative sets of features from available MSTAR and TRUMPETS data. We are generating two primary sets of features:

- a) Model based features which presume:
 - Point scatterers are the dominant scattering phenomenon,
 - Targets are moving, and,
 - Clutter is stationary.
- b) Data driven features that are derived from wavelet-based signature analysis.

We are evaluating these features to determine which set(s) of features are robust to the differences between measured and synthetic data. Feature Set Evaluation (FSE) is accomplished using both conventional techniques (e.g., kNN) and a technique called Boundary Methods. Much of this work is being pursued jointly with the TRUMPET project, funded by DARPA, and managed by Dr. Dennis Healy (DARPA) and Dr. Rob Williams (AFRL/SN),

New classifier designs are being developed that use these features to construct classifiers and verify that the developed classifiers perform well when trained with synthetic data and tested on measured data. Moreover, we verify that the classifiers make efficient use of a limited set of stored templates in order to mitigate computational problems.

Classifier Design

1. Objectives

As noted earlier, our objective is to develop a design methodology for constructing HRR classifiers that perform well when trained on synthetic data and tested on measured data. In particular, the methodology should result in an efficient classifier that uses robust features, i.e., the classifier should be more forgiving than, e.g., a Mahalanobis distance classifier, with respect to differences between measured and synthetic signatures.

2. Status of Effort

ATR systems required to operate under a broad class of scenario variations will employ high-dimensional data, such as HRR data. While this type of data improves discriminability, it also complicates classification because it leads to very large databases. The problems associated with reliance on these large databases are further exacerbated in applications where real-time performance is critical and only modest computational resources are available, e.g. as in ATR systems being considered for aircraft, e.g., UAVs, and mobile land vehicles. Therefore, managing the size and structure of such ATR databases represents one of the fundamental problems facing ATR designers. A possible solution to the above challenges is compression of the HRR target/signature database, which can be accomplished in two different ways:

- a) Feature Extraction, or.
- b) Vector Quantization (VQ) or similar clustering techniques.

While a reduction in the size of a database cannot add information, it can provide the means to reduce the number of templates necessary to reach a given confidence level, or we can trade-off mild degradations in classification performance for significant savings in computation and storage.

We have developed a new algorithm to train a Euclidean norm Vector Quantizer for classification. The algorithm takes as its objective function the average risk of the VQ classifier instead of the Mean Squared Error (MSE) criterion. Unlike the MSE, which is better suited to signal representation applications, the average risk is a generalization of the Bayes error and thus, it is a more appropriate criterion for classification. In addition, the resulting update equations for codevectors bear a striking resemblance to the update equations of Kohonen's Learning Vector Quantization (LVQ) techniques and thus lend insight into the widespread popularity and empirical success of the various LVQ algorithms.

3. Accomplishments

We have developed a taxonomy of statistical classification algorithms. In this taxonomy the fundamental technique in each of the four possible categorizations along the parametric/nonparametric and informative/discriminative are delineated. This taxonomy, while not exhaustively covering the plethora of classification algorithms that exist in the statistical pattern recognition literature, represents a concise grouping of the most prominent techniques. The taxonomy also provides insight and helps to explain how our work on VQ classifiers relates to other efforts in the field.

The discriminative techniques (discriminant analysis and voting k-NN), and Classification and Regression Trees (CARTs) in the taxonomy have strong ties to VQ classifiers in the way they generate decision boundaries. We have also established the theoretical relationship between the Euclidean distance (MSE) VQ and Piecewise Linear Discriminant machines (PLDMs). Additionally, we have established the equivalence between power-distance (Euclidean distance modified by an additive term) VQ classifiers and PLDMs. These relationships are used to explain how VQ classifiers can achieve a smoothly controllable balance between computational complexity and expressive power.

In our VQ classification algorithm, the gradient of the average risk with respect to codeword locations was formally derived. A stochastic gradient descent based on a sample-based estimate of the gradient has been implemented in MATLAB. Experimental results demonstrate that this novel gradient descent algorithm improves on initial states derived through other competing VQ classification techniques, and approaches Bayes optimal performance. Therefore, improved classification is achieved at the same or higher levels of data compression.

We have submitted a paper for publication in the IEEE Transactions on Pattern Analysis and Machine Intelligence. In this paper, the relationships between VQ classifiers and Discriminant Machines are presented as theorems. These relationships, and the exponential increase in the parametric complexity of Generalized Discriminant Machines as a possible alternative, are used to catapult VQ classification as a viable piecewise linear classification platform.

Finally, a study comparing the performance of our novel gradient descent VQ classification algorithm to that of other prominent VQ classifiers was performed, and we have demonstrated that our new gradient descent VQ classification performance is superior to the alternatives.

4. Personnel Supported

Stanley C. Ahalt, PI.
Batuhan Ulug, Graduate Research Assistant

5. Technical Publications

5.1 Journal Publications (listing only recent related papers)

- a) B. Ulug, S. C. Ahalt, "A Gradient Descent Training Algorithm for VQ Classification", submitted to IEEE Transactions on Pattern Analysis and Machine Intelligence, April 1999.
- b) J. L. Sancho, William E. Pierson, Batu Ulug, Stanley C. Ahalt, and A. R. Figueiras-Vidal, "Class Separability Estimation and Incremental Learning using Boundary Methods," submitted Dec. 1998 to Special Issue of Neurocomputing, accepted, in press.
- c) B. Pierson, and B. Ulug, and S. C. Ahalt and J. L. Sancho and A. Figueiras-Vidal, "On the Use of Boundary Methods for Measuring Class Separability," submitted Nov. 1998 to IEEE Transactions on Pattern Analysis and Machine Intelligence, under revision.
- d) B. Ulug, S. C. Ahalt, and R. A. Mitchell, "Efficient ATR Using Compression", IEEE Transactions on Aerospace and Electronic Systems, vol. 33, no. 4, pp. 1199-1211, October 1997
- e) J. Ma, and S. C. Ahalt, "2D HRR Radar Data Modeling and Processing," To be submitted to Multidimensional Systems and Signal Processing, special issue on Radar Signal Processing and its Applications.

5.2 Conference Proceedings (listing only recent related papers)

- a) J. Ma, and S. C. Ahalt, "Analysis of Complex HRR Range Signatures," Proceedings of SPIE International Symposium on Targets and Backgrounds VI, (Orlando, FL) April 24-28, 2000.
- b) J. Ma, and S. C. Ahalt, "Parameter Estimation Algorithms Based on a Physics-based HRR Moving Target Model," Proceedings of SPIE International Symposium on Algorithms for Synthetic Aperture Radar Imagery VII, (Orlando, FL) April 24-28, 2000.
- c) J. Ma, and S. C. Ahalt, "Derivation of Physics-based HRR Moving Target Model," Proceedings of SPIE International Symposium on Signal Processing, Sensor Fusion, and Target Recognition IX, (Orlando, FL) April 24-28, 2000.
- d) J. Ma and S.C. Ahalt, "Target Parameter Estimation Based on 2D HRR Radar Data," Proceedings of IEEE International Symposium on Intelligent Signal Processing and Communication Systems, (Honolulu, Hawaii), to appear, November 5-8, 2000.

5.3 Reviewed Conference Proceedings (listing only recent related papers)

- a) B. Ulug and S. C. Ahalt, "HRR ATR Using VQ Classification," Conference on "Automatic Target Recognition IX," SPIE's AeroSense '99 Orlando, Florida, April 5-9, 1999.
- b) W. E. Pierson, B. Ulug, and S. C. Ahalt, "Boundary Methods for mode Estimation, Conference on "Algorithms for Synthetic Aperture Radar imagery VI," SPIE's AeroSense '99 Orlando, Florida, April 5-9, 1999.

6. Interactions/Transitions

6.1 Conference Presentations

- a) Presentations at SPIE Aerosense 1999: 1) "HRR ATR Using VQ Classification", 2) "Boundary Methods for mode Estimation".
- b) Invited presentation in Madrid, Spain, Universidad de Carlos III, "Feature Generation, Evaluation, and Analysis," September, 1999.
- c) Presentations at SPIE Aerosense 2000: 1) "Analysis of Complex HRR Range Signatures", 2) "Parameter Estimation Algorithms Based on a Physics-based HRR Moving Target Model", and 3) "Derivation of Physics-based HRR Moving Target Model".

6.2 Transitions

a) Software for HRR Template Matching Classification and Data Generation is freely available on the internet at URL: <http://er4www.eng.ohio-state.edu/~ulugb/afosr/>
This has been made available to allow researchers to use our code in their applications. The following researchers have, to the best of our knowledge, been actively using the software.

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b) OSU Support Vector Machines (SVM) Classifier Toolbox, a software package for constructing and using SVM classifiers, is freely available on the internet at URL: http://eewwww.eng.ohio-state.edu/~maj/osu_svm/

The following researchers have, to the best of our knowledge, been actively using the software.

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7. Patent Disclosures
None

8. Honors
Stan Ahalt was the recipient of the OSU College of Engineering Research Accomplishment Award in 1999.